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Energy Conservation by High-Level Control made by Work Sites

Fuji Oil Company, Sodegaura Refinery
Refining Section 2, Production Division
APC Promotion Team

◎ **Keywords: Rationalization of heating, cooling and heat transfer (Heating equipment, etc.)**

◎ Outline of Theme

For the purpose of energy conservation and high-efficiency operation, we introduced high-level control to the normal paraffin production system of our refinery based on our policy that our own operators should design, build and operate systems which we use and transfer those system technologies to the next generation without relying on outside engineers as much as possible. As a result, we could establish a system in which our work sites could inherit achievements of our production systems and further improve them even if product needs change or production facilities are modified. We would like to report how the high-level control was built and how we achieved the energy conservation.

◎ Implementation Period for the said Example

(August 2007 – end of May 2008)

- Project Planning Period (August 2007 – November 2007)
- Measures Implementation Period (October 2007 – end of February 2008)
- Measures Effect Verification Period (March 2008 – end of May 2008)

◎ Outline of the Business Establishment

- Items Produced: LPG, gasoline, kerosene, light oil, heavy oil, asphalt, chemical products
- No. of Employees: 344 persons
- Type 1 designated energy management factory

◎ Outline of Target Facilities

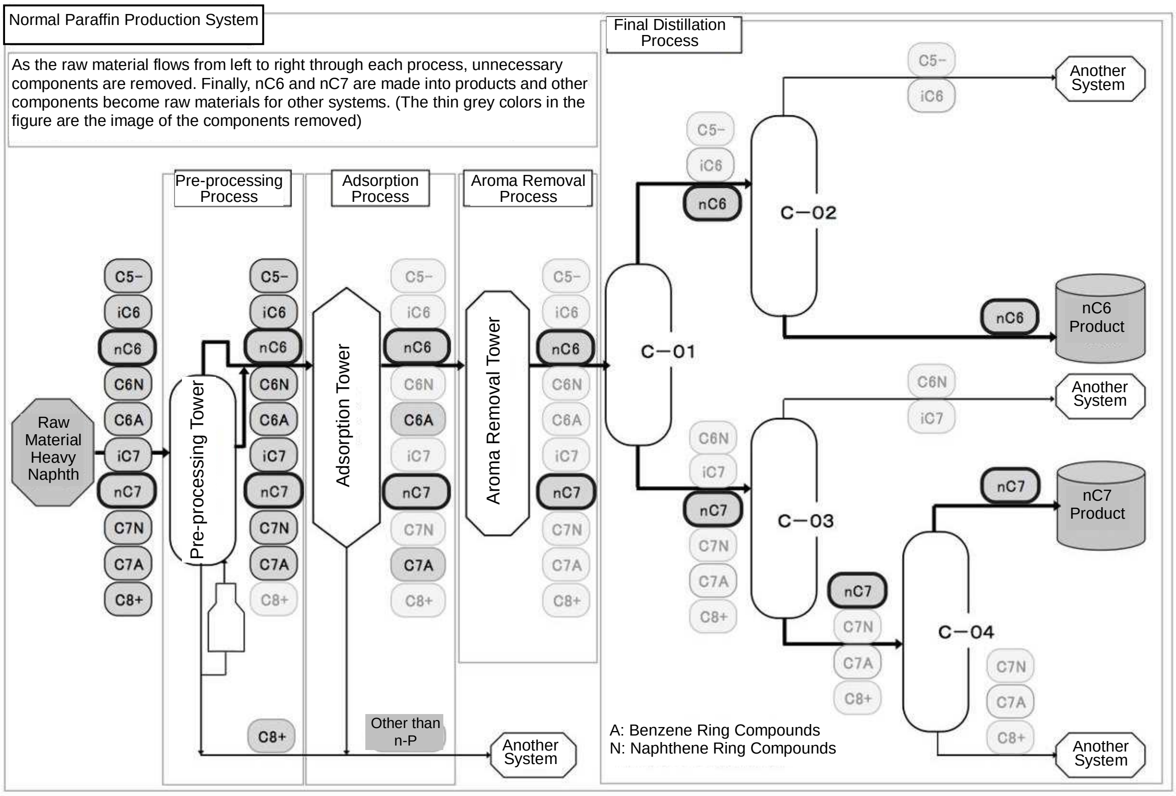


Fig. 1

1. Reasons for Theme Selection

Our section introduced the high-level control to the normal paraffin production system which requires precise distillation operation. At the same time, we newly installed feed component analyzers in order to always know components in the raw material. So we made it the theme of this case study to achieve energy conservation by doing above mentioned measures and realize efficient and stable operation.

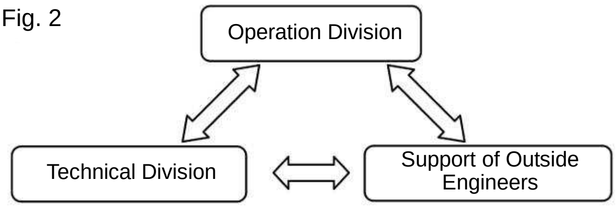
Besides, our operators used various tools such as a property estimation system, multivariable model predictive control system or operation support system to build the high-level control. By doing so, we aimed to not only inherit engineering technologies, maintain the energy conservation operation and do automatic quality control but also to manage and expand the system and improve the maintainability of the system.

2. Progress of Activities

(1) Implementation Structure

We built a collaborative implementation structure in our organization as shown in Fig. 2. Two people of the operation division receive advices and basic ideas concerning the control strategy from the technical division. They also receive technical supports concerning the input and output to and from upper-level computers and various types of software from outside engineers.

Fig. 2



(2) Understanding of Current Situation

The outline of the system is shown in Fig. 1. We explain it following the flow of the raw material.

The raw material of the system is a heavy naphtha of the components shown in Table 1 below. Of these components, nC6 and nC7 (normal paraffin) become products, so our work is to extract them efficiently and in a very pure state from the raw material.

Component	C5-	iC6	**nC6**	C6N	C6A	iC7	**nC7**	C7N	C7A	C8+
%(mass)	1.1	5.2	**5.7**	5	1.2	8.1	**8.1**	9.6	4.6	51.4

Table 1

The raw material is first processed in the “pre-processing process”. Here in the distillation tower with a heating furnace as the thermal source, the raw material is divided into a light component which is taken out from the tower top, a medium component which is taken out from the tower middle and a heavy component of C8 or more which is taken out from the tower bottom. Of these components, part of the component taken out from the tower top and the component taken out from the tower middle become the raw material of the next “adsorption process”.

The next “adsorption process” is a unique process of the normal paraffin production system. There are 3 adsorption towers filled with zeolite. The raw material is heated in the heating furnace and becomes gas. When the raw material gas goes through the adsorption tower, only the normal paraffin is absorbed. To collect the absorbed normal paraffin, batch processing is done which changes the equipment from the adsorption tower to a vacuum compressor to adsorption and release the paraffin.

The next "aroma removal process" turns the aroma component to hydrogen with aroma removal catalyst until it becomes 10 ppm or less.

Then, at the "final distillation process", we produce the highly pure products in 4 distillation towers watching the component analyzers.

At "C-01", nC6 and the light component are sent to "C-02" from its tower top and the component heavier than C6N is sent to"C-03" from its tower bottom.

At "C-02", the component lighter than nC6 is taken out from the tower top, so the cN6 as product can be taken from the tower bottom.

At "C-03", the component lighter than nC7 is taken out from the tower top and the remaining is taken out from the tower bottom and sent to "C-04". At "C-04", the component heavier than nC7 is taken out from the tower bottom and nC7 as product is taken out from the tower top.

In the current situation, there are 2 major problems.

The one is that there is a component analyzer in the "final distillation process" so we can always control the purity of the product, but there is no component analyzer in the "adsorption process" in the upper stream. So we have to adjust the component in the "pre-processing process" to make the normal paraffin maximum according to the component analysis result made twice a week. However, the components in the raw material are known only twice a week by the analysis, making it difficult to promptly respond to the change of the components.

The other problem is that although there is a vacuum compressor in the "adsorption process" for absorbing and releasing the normal paraffin, if the heavy component increases in the raw material, it may liquefy and cause emergency stop of the compressor. To avoid this, we need to remove the heavy component carefully in the "pre-processing process".

(3) Analysis of Current Situation (Operation after installing analyzer)

We increase or decrease the amount of the raw material or amount of the components to be taken out watching the component analyzer to maintain the purity and amount of the product at maximum, all by manual work.

Before this case study, we used to perform the adjusting operation 900 times a year.

Meanwhile, in the process for removing the heavy component in the pre-processing process, there is a risk of emergency stop as mentioned above, so we have to nervously adjust the operation, observing the reflux ratio and making the amount of the raw material slightly more so that the heavy components do not come in the component taken out from the tower middle. This makes the amount of the fuel gas used in the heating furnace increase to around 700 m^3_N/h.

(4) Target Settings

a. Cut of manual work

We always need to know the change of the raw material and automatically control the product quality. However, since the system is vulnerable to weather conditions, it is practically impossible to totally eliminate the manual operation for increasing or decreasing the amount of the raw material or adjustment of the operation for maintaining the product purity. So we try to make it 1/4 or less.

b. Cut of fuel amount used

We aim to reduce the fuel gas amount used by the heating furnace by 25 m^3_N/h or more by knowing the components of the raw material and by reducing the reflux ratio of the pre-processing process.

(5) Problem Points and their Investigation

We spend a lot of time and labor for the control of the product amount or management of the product quality. So we decided to introduce the high-level control and the operation support system into entire operations.

(6) Details of Measures

Since there are a lot of techniques for the high-level control, here we only describe 4 tools we used, then we describe the flow for building the high-level control.

“Property estimation tool”

There are 3 component analyzers installed in the normal paraffin production system, but it takes more than 30 minutes to output measured values. So we use the property estimation tool “RQE” which guesses the property of the fluid in operation from the flow rate, pressure, temperature, etc. and the result of the estimation is verified by the values of the analyzers or periodic tests.

This tool consists of an operation data analysis tool and an execution monitor tuning tool in the DCS. Fig. 3 shows the example of the actual property estimation as well as the trend of the values of the nC7 density analyzer and the RQE estimation.

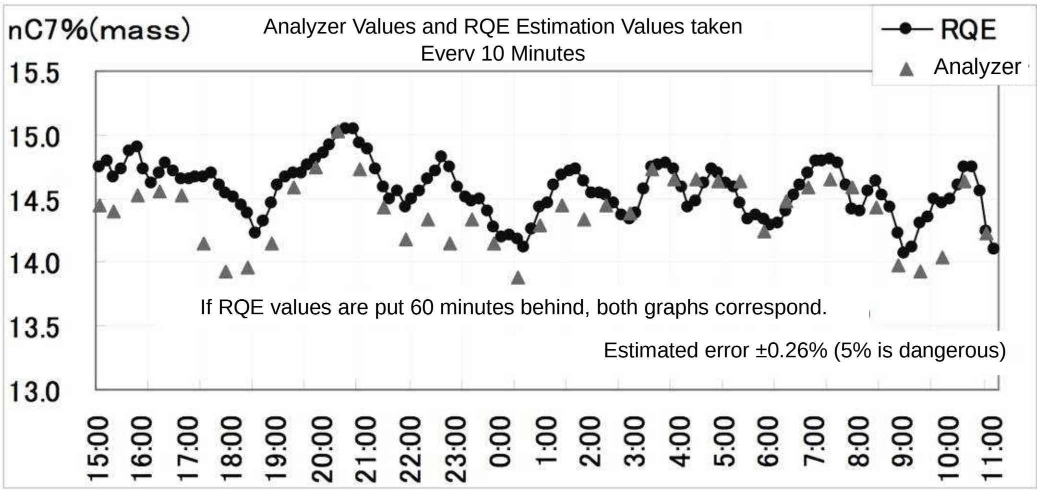


Fig. 3

Fig. 3 shows the RQE values delayed by 60 minutes. Then, they almost correspond to the values of the analyzer, indicating that the RQE estimated highly reliable values 60 minutes earlier. In this case study, we built the property estimation with 15 points for practical use.

“Multivariable model predictive control”

We used the multivariable model predictive control (SMOC) as a control tool.

This is not theoretically difficult. Try to operate it with the flow rate, pressure, temperature, etc. like doing a test and, as a result, it analyzes and registers the correlation between them like saying that the property, temperature, pressure, etc. changes C% in B minutes after A minutes (called modeling).

Then, we set the reference values such as temperature or pressure to be observed as restriction and fix the order of preference by simulation. Then, the control becomes possible. As a tool, this is more difficult than the RQE, but by repeating the test, it becomes fully understandable.

“Operation support system”

We used “ExaPilot” to support the setting values of the SMOC.

This tool has been used in other systems since 2003. It is not good for the direct control, but it is successfully being used in other systems for the interval control. It is easy to build but it needs to incorporate a common security concept.

“Data acquisition”

We used "PI-Datalink (Excel ad-in)" for the acquisition of data. It is used for the real operation by the high-level control or for the confirmation of the preciseness of values estimated by the RQE.

"Control strategy"

Before starting the high-level control, a control strategy must be made from the viewpoint of "what for", "what" or "how".

In this work, we need to carefully plan and clarify the scope of the control, the control method, the scope of the test, applicable standards and problems to be solved and make the process for creating the entire high-level control.

The control strategy was fully studied and corrected by the Technical Division and the Operation Division.

"Creation of property estimation"

First, we create the RQE and correct the delay of 30 minutes or more of each component analyzer. Using the tower's pressure, temperature or other variables, we estimate the density of each component and confirm the accuracy.

"Modeling of system"

We make each process into a model by conducting a step response test.

First, we make the test process static. From there, we increase the steam of the thermal source 10 kg/h by one-action.

The result comes out as changes happening everywhere in and out of the system like "after 10 minutes, the tower top temperature increased 0.2℃ in 40 minutes" or "after 20 minutes, the estimation of the heavy component of the tower top increased 0.1% in 20 to 60 minutes".

Besides, the test is conducted for "feed amount", "tower pressure", "reflux amount", "taking-out amount", etc.., to create one model. Then, we register these values changed as parameters.

Fig. 4 shows an example of "C-02". Each of the small graphs shows the response wave from of the test.

X axis expresses the time and Y axis expresses the result such as temperature or estimated property. They show how the change starts slightly later and stops.

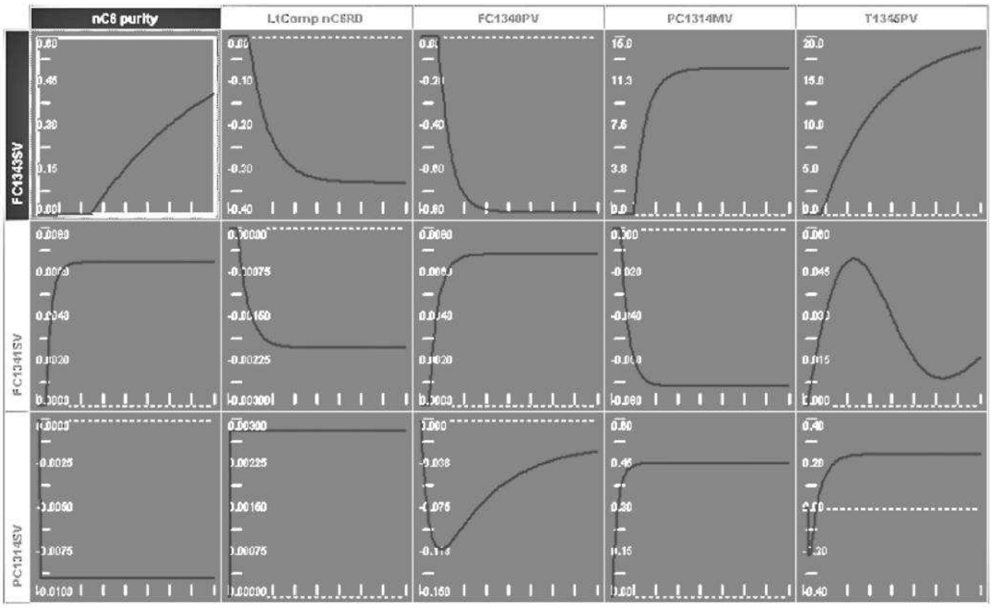


Fig. 4

"Setting of restriction and simulation"

When the model is created, each target value and restriction value is set. There are items such as upper and lower limits of the temperature, upper and lower limits of the product standard, setting of the energy conservation. The order for observing these items is set one by one by confirming them with simulator software.

"Link with upper-level computers"

To do control with the SMOC, these results must be set in the upper-level computers of the DCS and executed.

This work required cooperation of outside engineers, but we could master the skill to cope with almost every change because we worked it out together with a lot of jobs.

"Example of energy conservation"

The model predictive control is a system for setting target values and living up to them. As the example of the activities to improve the target value, we explain the activities to prevent the raw material of the "adsorption process" from becoming heavy component and to cut the fuel gas of the "pre-processing process", which also contributed to the energy conservation. We newly installed a component analyzer to the entrance of the "adsorption process" and focused on the C8+ and C7A which are heavy components among those components. We paid special attention to the increase of C8+ because the problem of the material turning into heavy component must be watched with special care.

In the graph of Fig. 5, X axis expresses the reflux ratio and Y axis expresses the ratio of heavy components.

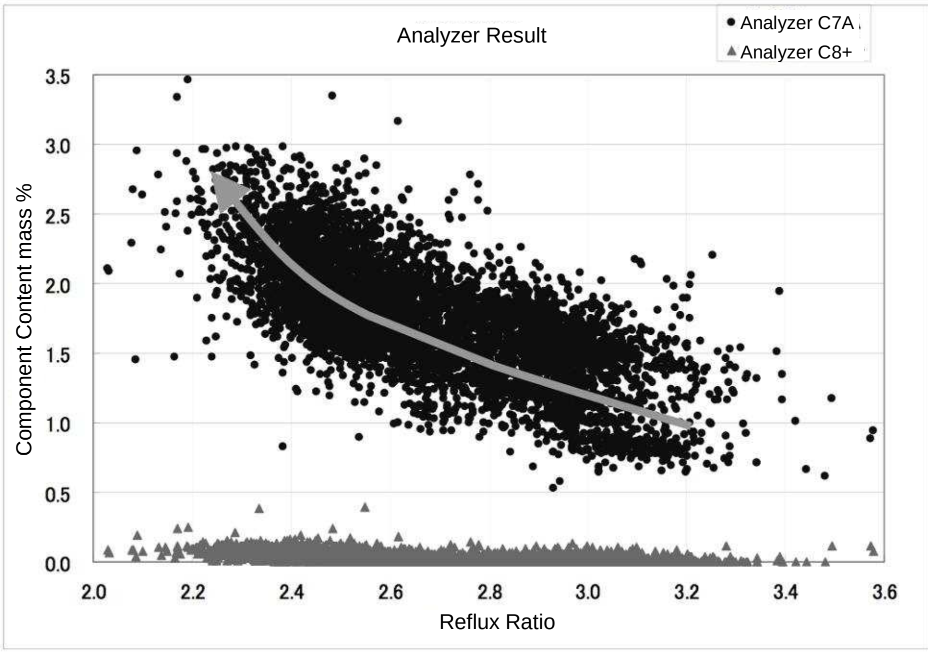


Fig. 5

As the reflux ratio comes down, the heavy component ratio goes up, and when the reflux ratio comes below around 2.4, C7A becomes likely to increase. Meanwhile, C8+ does not change much, and it is found that the range of 2.8 to 3.2 which is too much for the reference value of the reflux ratio. During the test, the increase of the heavy component did not affect the “adsorption process”, and it was possible to reduce the reflux ratio.

(7) Result of Measures

Throughout activities of this case study, we tested the SMOC control model as described in the foregoing paragraph (6) dividing it into 4 sections, i.e. “pre-processing process”, “C-01”, “C-02”, “C-03” and “C-04”, and built and started to operate it.

As regards the activities to reduce the usage of fuel gas, we could make a system which maintains the energy conservation and prevents the material from becoming heavy component while decreasing the load of the heating furnace, because we adopted a new reference value for the reflux ratio as the restriction condition in the pre-processing process of the SMOC.

(8) Effects achieved after Implementing Measures

a. Cut of manual operation

After introducing the high-level control, the number of the taking-out operation became 90 times/year, which was 1/10 the number before the introduction. Even if adding the number of the new operation by 105 times/year, caused by the high-level control introduced, the total number of the operation was 195 times/year, so we achieved 1/4 or less as our target.

Fig. 6 is the graph of the taking-out done to maintain the purity before and after the introduction in the "final distillation process". It is noted that before the introduction, the flow rate changed like steps because it was manual work and there were operations forgotten and loss caused by excessive taking-out. After the introduction, the manual work was eliminated and only necessary amount started to be taken out.

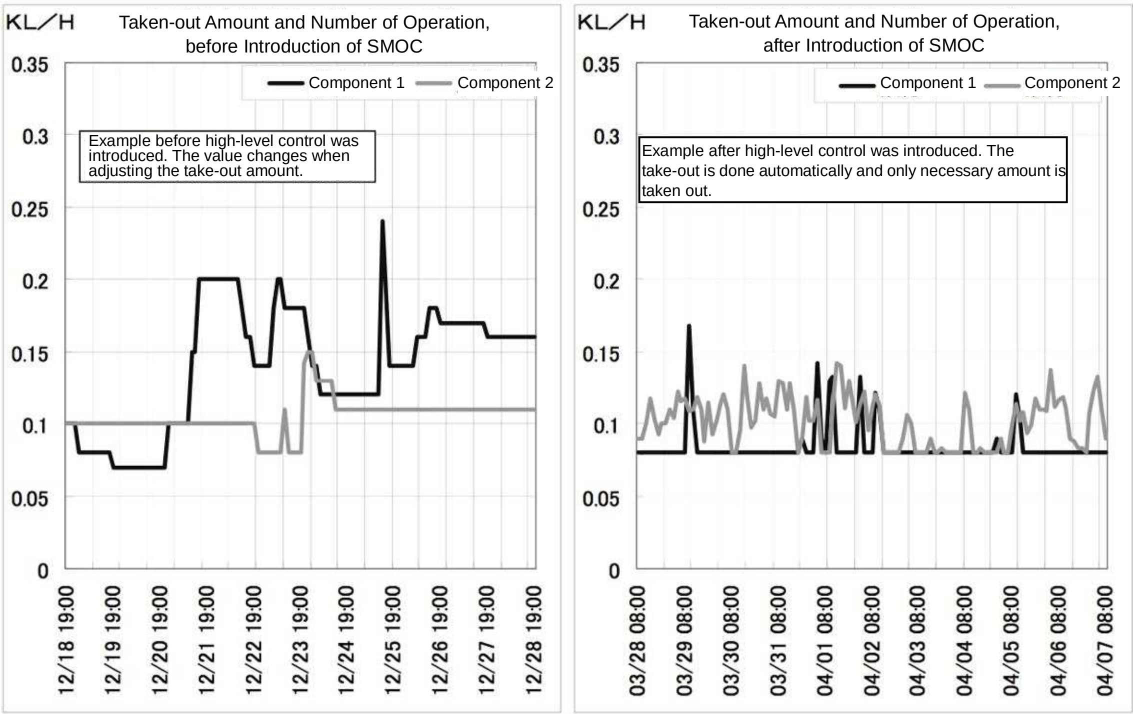


Fig. 6

b. Cut of fuel oil amount used

As a result of the activities to reduce the reflux ratio, it was found that the ratio was enough at around 2.4, so we maintained this value. Fig. 7 shows how much of the fuel use was cut then.

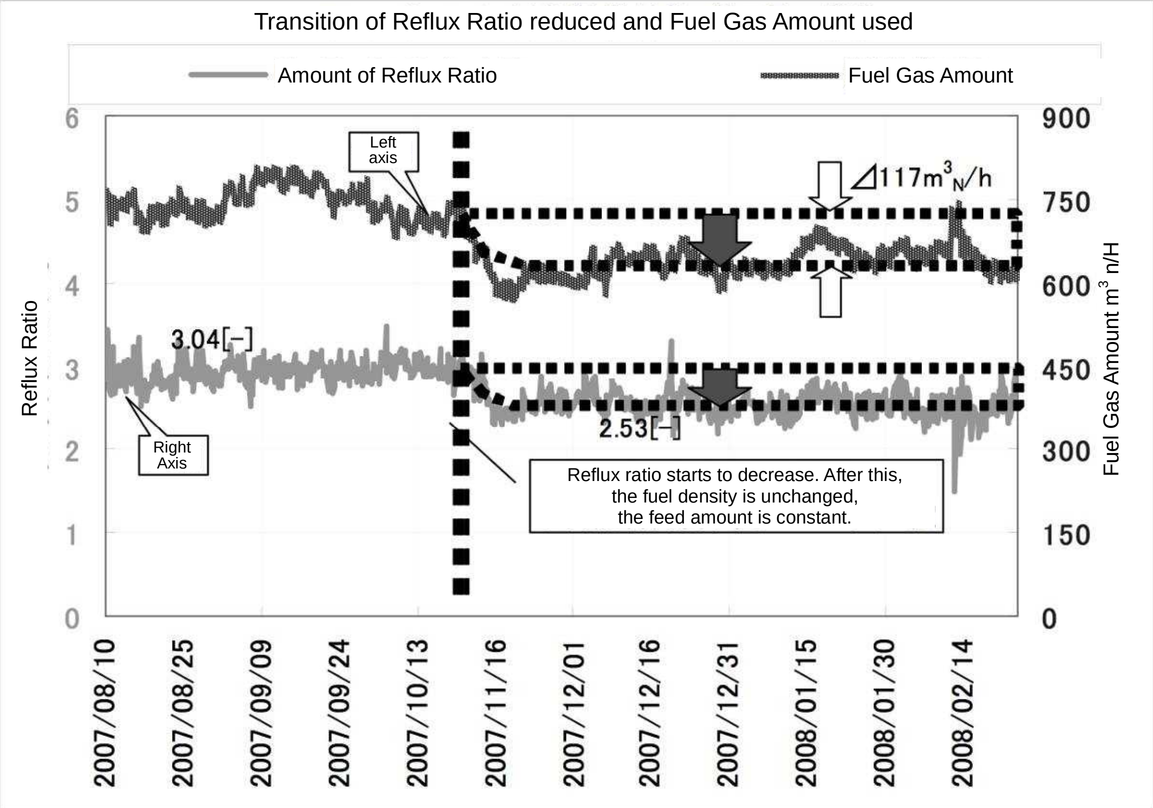


Fig. 7

The horizontal axis expresses the date, the left axis expresses the reflux ratio and the right axis expresses the change of the fuel gas amount used. After starting the test, we reduced the reflex ratio in about 2 weeks. Other conditions are unchanged during the test.

The graph shows that when the test started, the amount of the fuel gas decreased and it was maintained. The reflux ratio was 3.04 before the test and decreased to 2.53 in average after the test, and the amount of the fuel gas decreased 117 m^3_N/h in average.

Due to these activities, approximately 20% of the fuel used in the normal paraffin production system was cut, but, as the fuel used decreased, the gas discharge also decreased and the steam amount generated by the waste heat boiler at the down stream of the heating furnace decreased. Considering all of them, energy conservation as much as 530 kL/year converted to crude oil and 1080 t/year CO_2 emission was achieved.

Meanwhile the pay-out of the equipment investment was as short as 1 year.

Table-2 shows the energy conservation effect of the activities of this case study.

Items	Energy Usage Reduction Effect	
	Crude Oil Equivalent kL/year	CO_2 Reduction t/year
Reduction of Heating Furnace Fuel	1190	2400
Reduction of Steam Generated by Waste Heat Boiler (Disadvantage)	-660	-1320
Total	530	1080

Table 2

3. Summary

To implement the high-level control, we operated 4 SMOCs and 15 RQEs and, as a result, there were 4 effects as follows.

(1) We installed an analyzer at the entrance of the “adsorption process” and we could achieve energy conservation of the “pre-processing process” (530 kL/year crude oil equivalent).

(2) We implemented the property estimation of the RQE for every distillation tower and achieved the quality control by the introduction of the SMOC and succeeded in making the energy conservation control automatic.

(3) In the “adsorption process”, using the values of the newly installed analyzer, we changed the way to change the adsorption tower from “the change when the temperature changes” to “the change according to the component existing around the entrance of the adsorption process”. By doing this way, we strengthened the response to the change of the composition using the RQE and the ExaPilot.

(4) The product collection rate changes as the components in the raw material routinely change. We made the system which optimizes the feed amount by informing such change to the “pre-processing process”.

(5) We completed this case study by the development efforts of our operators. So the operators became able to lead the maintenance and expansion of the system functions. It is now possible not only to inherit the effect of the improvement and but also to promote continuous improvement.

4. Future Plans

Once the high-level control is built, it is very difficult that “everybody understands” the

system thus built. Although old manual work is eliminated by making the system automatic, new skills must be mastered to cope with the system trouble or to do the maintenance of the instruments newly introduced. These skills are not sufficiently mastered only by manuals or introductory training. It is important to train people concerned through the OJT.
Meanwhile, we will incorporate the high-level control to the systems one by one which do not have one yet.